

UPPER COLUMBIA BASIN NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE UPPER COLUMBIA BASIN NETWORK

October 2001

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to -4.0 , a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

Literature Cited

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. *Environmental Management*. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. *Atmospheric Environment* 31(11):1695-1708.

U.S. National Park Service. 2003. Ozone Sensitive Plant Species on National Park Service and US Fish and Wildlife Service Lands. NPS D1522. Natural Resource Report NPS/NRARD/NRR-2003/01. Air Resources Division. Denver, CO. 21 pp. (Available at www2.nature.nps.gov/ard/pubs/index.htm)

SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE UPPER COLUMBIA BASIN NETWORK

Park	Code	State	Risk	O3 Data
Big Hole NB	BIHO	MT	low	kriged
City of Rocks N RES	CIRO	ID	moderate	kriged
Craters of the Moon NHP	CRMO	ID	low	monitored
Hagerman Fossil Beds NM	HAFO	ID	low	kriged
John Day Fossil Beds NM	JODA	OR	low	kriged
Nez Perce NHP	NEPE	ID	low	kriged
Whitman Mission NHS	WHMI	WA	low	kriged

BIG HOLE NATIONAL BATTLEFIELD (BIHO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicacea

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BIHO					
	1995	1996	1997	1998	1999
Sum06	5	13	7	13	13
W126	13.6	19.5	13.2	22.1	20.8
N60	130	267	137	296	274
N80	13	22	6	26	8
N100	2	3	1	4	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BIHO					
	1995	1996	1997	1998	1999
Month 1	-1.20	-0.18	1.57	-0.86	-1.61
Month 2	3.04	2.69	0.34	-0.51	-1.81
Month 3	2.82	3.10	0.76	4.18	-1.48

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BIHO					
	1995	1996	1997	1998	1999
April	3.76	0.19	1.27	0.43	-0.25
May	1.84	3.87	0.15	0.07	1.20
June	2.83	-2.69	1.89	4.35	-0.26
July	4.77	-1.51	3.81	1.95	-2.53
August	2.44	-2.21	2.95	-0.40	1.55
September	0.59	-1.27	0.20	-1.48	-2.24
October	1.76	-0.44	2.10	-0.81	-2.63

Risk Analysis

- There are two ozone-sensitive species at the site, both of which are bioindicators for ozone.
- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Three years, 1996, 1998 and 1999, had the same highest Sum06 index of exposure. Soil moisture was normal in 1996 and 1998, and there were three months of mild drought in 1999. The remaining two years had one month of mild drought between them. No relationship is apparent between the W126 index of exposure and soil moisture. The year with the highest exposure, 1998, experienced one month of mild drought, while the second highest year, 1999, had three months of moderate drought. The mid-level exposure year 1996 had four months of mild

and moderate drought, and the two lowest exposure years had normal soil moisture conditions.

The risk of foliar ozone injury at Big Hole National Battlefield is low. The threshold levels for injury are not consistently satisfied by the Sum06 and not satisfied by the W126 index of exposure. The N-value counts indicate there are a few hours of exposure to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. Soil moisture levels are not associated with ozone exposure, however some years have periods of drought that significantly constrain uptake and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use the following bioindicator species: ponderosa pine and quaking aspen.

CITY OF ROCKS NATIONAL RESERVE (CIRO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Salix scouleriana</i>	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CIRO					
	1995	1996	1997	1998	1999
Sum06	9	19	10	17	16
W126	18.8	28.1	16.4	28.5	24.4
N60	247	470	246	449	388
N80	28	57	16	76	31
N100	4	7	2	12	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CIRO					
	1995	1996	1997	1998	1999
Month 1	0.19	-2.20	0.21	3.20	0.83
Month 2	2.43	-0.51	0.47	2.83	0.88
Month 3	2.00	-2.41	3.63	2.05	1.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CIRO					
	1995	1996	1997	1998	1999
April	0.19	-0.22	0.90	-0.14	1.85
May	2.43	4.64	0.21	3.20	2.45
June	2.00	-2.20	0.47	2.83	0.83
July	2.37	-0.51	3.63	2.05	0.88
August	0.46	-2.41	2.75	0.21	1.35
September	-0.93	-0.24	2.12	1.60	-1.12
October	-0.68	-0.25	0.47	-0.14	-1.84

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had twelve hours in which the concentration exceeded 100 ppb. The highest levels of exposure may injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods were generally normal and favored the uptake of ozone. In the Sum06 assessment, there were two months of moderate drought stress in the year with the highest exposure, 1996, while the remaining four years had normal soil moisture. No associations between ozone and soil moisture can be discerned from these observations. Soil moisture levels associated with the seasonal W126 index of exposure were generally normal and favored the uptake of ozone. In

1996 and 1998, years with similar high exposures, there were two months of moderate drought and normal soil moisture conditions, respectively. The mid-level exposure year 1999 had two months of mild drought, and the lowest exposure years 1995 and 1997 had normal soil moisture. No clear relationship between ozone exposure and soil moisture can be derived from this pattern.

The risk of foliar ozone injury at City of Rocks National Reserve is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, and there are a few years in which the W126 criteria are fulfilled. Since there is no association between levels of ozone and soil moisture, conditions favorable for the uptake of ozone can occur at all levels of exposure. This creates the opportunity for reaching the threshold for injury at both high and more moderate levels of ambient ozone. The risk of injury is greatest in years such as 1998 when the ambient level of ozone is high, and soil moisture conditions favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use the following bioindicator species: quaking aspen and Scouler's willow.

CRATERS OF THE MOON NATIONAL HISTORIC PARK (CRMO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Salix scouleriana</i>	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
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W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CRMO					
	1995	1996	1997	1998	1999
Sum06	1	12	2	10	11
W126	12.2	19.9	9.8	22.7	5.4
N60	20	223	40	267	234
N80	0	5	0	0	2
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

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Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CRMO					
	1995	1996	1997	1998	1999
Month 1	1.12	-1.49	-0.05	3.52	1.91
Month 2	4.49	-0.21	1.05	3.11	1.12
Month 3	7.03	-1.66	3.38	2.15	1.52

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CRMO					
	1995	1996	1997	1998	1999
April	1.12	0.30	1.04	-0.26	2.33
May	4.49	2.95	-0.05	3.52	3.61
June	7.03	-1.49	1.05	3.11	1.91
July	5.41	-0.21	3.38	2.15	1.12
August	3.05	-1.66	3.01	-0.99	1.52
September	-0.15	0.41	1.59	1.92	-1.66
October	-0.71	-0.55	0.60	-0.70	-1.57

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value generally exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show only two years in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels were generally normal and favored the uptake of ozone. Four months of mild drought were distributed among two of the years. With this incidence of drought, it is not possible to determine whether a relationship exists between the level of soil moisture and either the 90-day cumulative Sum06 or the seasonal W126 index of exposure.

The low levels of ozone exposure at Craters of the Moon National Historic Park make the risk of foliar ozone injury to plants low. The Sum06 exposures intermittently exceed the threshold for injury, but the W126 exposures do not since the N100 criterion is not satisfied. While soil moisture levels are generally favorable for the uptake of ozone, ambient levels of exposure are such that the threshold for foliar injury is not likely to be reached.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, quaking aspen, and Scouler's willow.

HAGERMAN FOSSIL BEDS NATIONAL MONUMENT (HAFO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Rhus trilobata	Skunkbush	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HAFO					
	1995	1996	1997	1998	1999
Sum06	7	17	8	15	14
W126	16.8	25.8	14.8	27.1	24.7
N60	177	398	192	402	350
N80	19	43	12	56	24
N100	2	5	1	9	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HAFO					
	1995	1996	1997	1998	1999
Month 1	0.40	1.24	0.01	6.72	1.70
Month 2	4.41	1.59	2.75	3.71	1.48
Month 3	5.76	-0.74	2.18	3.27	1.01

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HAFO					
	1995	1996	1997	1998	1999
April	0.40	0.19	1.56	-0.28	2.30
May	4.41	3.91	0.01	6.72	2.04
June	5.76	1.24	2.75	3.71	1.70
July	4.57	1.59	2.18	3.27	1.48
August	1.04	-0.74	1.02	0.10	1.01
September	-0.10	-0.94	1.43	2.39	-1.39
October	-0.63	0.16	0.31	-1.40	-1.47

Risk Analysis

- There are two ozone-sensitive species at the site, one of which is a bioindicator for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had nine hours in which the concentration exceeded 100 ppb; the second highest year had five hours. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods were generally normal and favored the uptake of ozone. In the five-year Sum06 assessment, there were no months of drought. Soil moisture levels during the W126 accumulation periods were also generally normal. In the five-year period, soil moisture was at mild drought for one month in the highest ozone year 1998, and for two months in a mid-level ozone year 1999.

The risk of foliar ozone injury at Hagerman Fossil Beds National Monument is low. The threshold level for injury is satisfied by the Sum06 index, and there is one year in which

the W126 criteria are fulfilled. Since there is no association between levels of ozone and soil, conditions favorable for the uptake of ozone can occur at all levels of exposure. The risk of injury is greater in years such as 1998 when ambient levels of ozone are high, and soil moisture conditions favor uptake by the plants.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use the bioindicator species skunkbush.

JOHN DAY FOSSIL BEDS NATIONAL MONUMENT (JODA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Pinus ponderosa	Ponderosa pine	Pinaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for JODA					
	1995	1996	1997	1998	1999
Sum06	3	9	3	6	4
W126	6.7	11.2	4.9	6.6	5.9
N60	85	152	47	87	69
N80	10	37	1	16	3
N100	2	9	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at JODA					
	1995	1996	1997	1998	1999
Month 1	0.60	1.10	-1.42	1.66	-0.70
Month 2	2.16	1.15	1.82	4.03	-0.56
Month 3	3.04	-0.32	-0.47	0.10	-0.12

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at JODA					
	1995	1996	1997	1998	1999
April	2.61	0.87	1.82	0.43	0.51
May	0.60	2.62	-0.47	7.10	-0.70
June	2.16	1.10	0.70	1.66	-0.56
July	3.04	1.15	1.94	4.03	-0.12
August	0.26	-0.32	0.28	0.10	2.16
September	-0.75	-0.19	0.41	0.52	-1.69
October	-1.33	-0.17	-0.15	-1.11	-0.17

Risk Analysis

- There are two ozone-sensitive species at the site, one of which is a bioindicator for ozone.
- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value marginally exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had nine hours in which the concentration exceeded 100 ppb; the second highest year had three hours. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods were normal and favored the uptake of ozone. In the five-year assessment period, soil moisture was at mild drought for one month. Soil moisture levels during the seasonal W126 accumulation periods were also generally normal. One month of mild drought occurred in each of three years without any association with the level of ozone exposure.

The low levels of ozone exposure at John Day Fossil Beds National Monument make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. Concentrations over 100 ppb are rare, but one year has a higher number of hours. Since there is no association between levels of ozone and soil, conditions favorable for the uptake of ozone can occur at all levels of exposure. The risk of injury is greatest in years such as 1998 when ambient levels of ozone are higher, and soil moisture conditions favor uptake by plants.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use the bioindicator ponderosa pine.

NEZ PERCE NATIONAL HISTORIC PARK (NEPE)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Artemisia douglasiana</i>	Mugwort	Asteraceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for NEPE					
	1995	1996	1997	1998	1999
Sum06	2	5	1	5	5
W126	8.9	11.7	7.3	11.4	10.1
N60	82	141	57	142	113
N80	6	13	3	9	3
N100	1	2	0	2	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at NEPE					
	1995	1996	1997	1998	1999
Month 1	1.96	-1.51	-0.97	2.75	-0.32
Month 2	-0.40	-1.07	-0.83	-0.18	0.47
Month 3	1.86	-1.60	3.60	1.47	-2.07

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at NEPE					
	1995	1996	1997	1998	1999
April	1.96	3.41	3.34	0.51	-0.85
May	-0.40	4.08	-0.97	3.85	-0.52
June	1.86	-1.51	-0.83	1.09	0.61
July	4.77	-1.07	3.60	2.75	-0.32
August	3.90	-1.60	1.24	-0.18	0.47
September	-0.07	0.09	1.03	1.47	-2.07
October	3.42	0.99	0.85	-0.37	0.01

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- The low and similar levels of ozone during the 90-day Sum06 and the seasonal W126 accumulation periods and the infrequent occurrence of low soil moisture make it impossible to assess relationships between the levels of ozone and soil moisture, and no patterns are evident. During the five-year W126 assessment period, there were four months of drought; three in one year and one in another. The periods of drought were not associated with the levels of ozone exposure in these years.

The low levels of ozone exposure at Nez Perce National Park make the risk of foliar

ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. There are some hours of exposure to concentrations of ozone above 80 ppb, however the numbers are not high. Exposure to concentrations over 100 ppb is rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, mugwort, ponderosa pine, and common snowberry.

WHITMAN MISSION NATIONAL HISTORIC SITE (WHMI)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Robinia pseudoacacia	Black locust	Fabaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WHMI					
	1995	1996	1997	1998	1999
Sum06	2	5	1	5	4
W126	7.8	10.3	6.4	8.2	7.7
N60	93	137	59	110	91
N80	9	21	4	13	3
N100	1	4	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WHMI					
	1995	1996	1997	1998	1999
Month 1	1.92	2.09	0.82	-1.50	-0.84
Month 2	3.02	2.94	1.15	0.59	-1.87
Month 3	3.86	-0.63	2.52	-1.35	-0.72

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WHMI					
	1995	1996	1997	1998	1999
April	3.17	1.32	1.15	-1.24	-1.92
May	1.92	2.75	2.52	0.86	-0.84
June	3.02	2.09	2.23	-1.50	-1.87
July	3.86	2.94	3.14	0.59	-0.72
August	0.76	-0.63	0.45	-1.35	0.12
September	1.54	-0.18	0.50	-1.40	-1.76
October	0.42	1.88	2.40	-1.58	-0.51

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value is marginally above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Low and similar levels of ozone during the Sum06 accumulation periods and only three months of mild drought over five years make it difficult to assess relationships between the levels of ozone and soil moisture, and no pattern is evident. In the W126 assessment period, drought was concentrated in two years: five months in 1998, the second highest year, and three months in 1999, the second lowest year. Ozone exposures over the five-year period were relatively similar, and no association between ozone and drought can be discerned.

The low levels of ozone exposure at Whitman Mission National Historic Site make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. There are some hours of exposure to concentrations of ozone above 80 ppb, however the numbers are not high. Exposure to concentrations over 100 ppb is rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: American sycamore, quaking aspen, and common snowberry.